

**BEARINGS**

5 The present invention relates to plain bearings and particularly, though not exclusively, to plain bearings having a strong backing layer, a layer of a first bearing material on the backing layer and a layer of a second bearing material on the layer of first bearing material.

10

Plain bearings for use as crankshaft journal bearings in internal combustion engines, for example, are usually semi-cylindrical in form and generally have a layered construction. The layered construction frequently 15 comprises a strong backing material such as steel, for example, of a thickness in the region of about 1mm or more; a lining of a first bearing material adhered to the backing and of a thickness generally in the range from about 0.1 to 0.5mm; and often a layer of a second bearing 20 material adhered to the surface of the first bearing material and having a thickness of less than about 25 $\mu$ m. The surface of the second bearing material forms the actual running surface with a co-operating shaft journal surface. The backing provides strength and resistance to 25 deformation of the bearing shell when it is installed in a main bearing housing or in a connecting rod big end for example. The first bearing material layer provides suitable bearing running properties if the layer of the second bearing material should be worn through for any 30 reason. Thus, the layer of first bearing material provides seizure resistance and compatibility with the shaft journal surface and prevents the journal surface from coming into contact with the strong backing material. As noted above, whilst the first bearing

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- material provides seizure resistance and compatibility, it is generally harder than the material of the second layer. Thus, it is inferior in terms of its ability to accommodate small misalignments between bearing surface
- 5 and shaft journal (conformability) and in the ability to embed dirt particles circulating in the lubricating oil supply so as to prevent scoring or damage to the journal surface by the debris (dirt embedability).
- 10 The first bearing material may commonly be chosen from either aluminium alloy or copper alloy materials. Aluminium alloys generally comprise an aluminium or aluminium alloy matrix having a second phase of a soft metal therein. The soft metal phase may be chosen from
- 15 one or more of lead, tin and bismuth. However, lead is nowadays a non-preferred element due to its environmental disadvantages. Copper based alloys such as copper-lead and leaded bronzes are also likely to fall into disfavour eventually due to these environmental considerations and
- 20 may be replaced by lead-free copper alloys, for example.
- The second bearing material layer which co-operates with the shaft journal is also known as an overlay layer and has been generally formed by a relatively very soft metal
- 25 layer. An example is lead-tin alloy deposited, for example, by electrochemical deposition. Such alloys, however, in addition to being undesirable environmentally are also prone to wear in modern highly loaded engine applications. In order to replace such overlay alloys
- 30 with lead-free, more wear resistant alternatives much work has been carried out on soft aluminium alloys having relatively high tin contents and which are deposited by techniques such as cathodic sputtering, for example. A disadvantage of such techniques is that such bearing
- 35 layers are expensive to produce, the process being an

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essentially small batch process due to the vacuum sputtering equipment required.

In order to solve the problems electro-deposited lead-tin  
5 alloys and later sputtering techniques, some workers have turned to polymer based overlays for oil lubricated, hydrodynamically loaded journal bearings.

JP-A-11106775 describes an overlay having a polymer  
10 matrix of a polyamidoimide resin and having 20 to 69.7vol% of a self lubricating phase therein. The examples show 28 to 63vol% of the self lubricating phase (molybdenum disulphide). The self lubricating phase may be selected from molybdenum disulphide, graphite,  
15 tungsten disulphide and the like.

JP-A-11106779 describes a similar material, the examples in this case containing from 30 to 70vol% of molybdenum disulphide, but where the resin matrix has a tensile  
20 strength in excess of 100Mpa.

However, a problem with such high contents of self lubricating materials of the types described is that whilst the frictional properties and the wear resistance  
25 of the material may be adequate, the fatigue strength is frequently impaired.

The present invention has been made to overcome the disadvantages of the prior art.  
30

According to a first aspect of the present invention there is provided a plain bearing having a sliding layer of a bearing material thereon, the bearing material comprising a polymer-based matrix selected from the group  
35 comprising modified epoxy resin and polyimide/amide

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resin, the matrix having contained therein at least one addition selected from the group comprising: metal powder in the range from 15 to 30vol%; a fluoropolymer powder in the range from 1 to 15vol%; ceramic powder in the range 5 from 0.5 to 20vol%; and, silica in the range from 2 to 15vol%.

Bearings according to the present invention are intended to operate in oil lubricated, hydro-dynamically loaded 10 applications such as internal combustion engine main and connecting rod bearings where the pattern of loading is extremely non-uniform, ranging from low load levels to very high peak loads within one complete engine cycle. Thus, bearing materials for such applications must 15 possess not only high strength per se, but also high fatigue strength to withstand the cyclic loading to which they are subjected and also very high levels of adhesive bond strength to the substrate on which the material is deposited.

20

In the applications intended, the temperatures experienced are generally higher than those to which plastics bearing materials are normally subjected. Moreover, the applications are oil lubricated thus, the 25 plastics materials must be resistant to the hot chemical additives employed in modern oils to maintain their lubricating qualities under the arduous conditions pertaining in modern high-performance engines.

30 In this specification the term "modified epoxy resin" is intended to cover a resin comprising from 30 to 60 w/w epoxy resin and 70 to 40 w/w phenolic resin based on solids to solids content. The phenolic component of the matrix resin provides good heat and chemical resistance 35 whereas the epoxy component whilst also being very

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chemically resistant also enhances flexibility of the bearing material layer and promotes improved adhesion to the substrate on which it is deposited.

- 5 The epoxy resin component itself may comprise two or more different epoxy resins.

The modified epoxy resin may also further contain amino resin so as to form an epoxy-amino-formaldehyde resin.

- 10 The amino resin component promotes curing and cross-linking of the epoxy resin and also promotes adhesion of the polymer to the substrate. Chemical resistance of the polymer is also enhanced by the amino resin component.
- 15 Further additions of a vinyl resin may also be made. The vinyl resin component has a softening effect on the resin matrix and endows the overlay layer with conformability enabling it to deform to accommodate minor misalignments between shaft journal and bearing surface, for example.
- 20 An example of a typical modified epoxy resin matrix may comprise: 53wt% epoxy/phenolic resin; 35wt% amino resin; 12wt% vinyl resin. This resin matrix composition is merely exemplary and the broader compositional ranges may
- 25 vary significantly around these figures.

In the case of the polyimide/amide matrix resin, the polyimide is a majority constituent. Polyimide resins have outstanding chemical resistance and also outstanding heat resistance, being able to withstand temperatures up about 400°C. Moreover the adhesive characteristics of polyimides to a substrate are also excellent. The polyimide/amide resin may also contain a vinyl resin component which has a similar conformability endowing

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effect as with the modified epoxy resin matrix.

A typical polyimide/amide matrix composition may comprise: 84wt% polyimide/amide resin; 16wt% vinyl resin.

5 This composition is merely exemplary and as with the epoxy resin matrix the broader compositional ranges may vary significantly around these figures.

The metal powder constituent is present due to the  
10 benefits conferred in terms of wear resistance in accommodating high bearing loads and also in improving the impact resistance ability of the bearing material in view of high firing loads generated during the operation of internal combustion engines.

15

The metal powder constituent may comprise a single powder of a pure metal such as aluminium, copper, silver, tungsten, nickel, for example, or may comprise a metal powder alloy such as brass, bronze, stainless steel, for  
20 example.

The metal powder constituent may itself comprise mixtures of different metal or metal alloy powders in preferred proportions. In one embodiment of a bearing material  
25 according to the present invention, the metal powder may comprise a mixture of aluminium and tungsten metals in the proportion of 40/60% Al/W by volume. However, the relative proportions may range between 30/70 and 70/30 Al/W depending upon the actual engine bearing application  
30 in question.

The powder morphology of each constituent may vary. In the example described above the W particles are nodular or rounded and this morphology for the very hard W  
35 particles has improved wear resistance due to a uniform

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distribution of these hard particles within the matrix. However, in general, flake or platelet type particle morphology is generally preferred even for the hard particles. Stainless steel powder having flake or 5 platelet morphology has been successfully used.

The softer Al powder constituent, and other softer metal powders such as brass, copper, silver and the like, may preferably be of flake or platelet morphology as this 10 provides a greater surface area and which particles tend to align themselves generally with the plane of the bearing material layer and so provide a high temperature lubricating effect in use. Alternatively, the Al constituent may also be of nodular particle morphology as 15 this has also been found to be beneficial in some situations.

In the case of the softer metal powders having platelet morphology, it is preferred that the generally pure metal 20 such as Al, Ag, or Cu, for example, is employed as the thermal conductivity of these materials is beneficial in conducting heat from the bearing into the housing in which it is held and also to the circulating lubricating oil for bearing cooling purposes.

25 The range of total metal powder content may be from 15 to 30vol%. Below 15vol% the improvement in wear resistance is insufficient whereas above 30vol% the bearing material becomes too hard and porosity tends to be produced in the 30 layer which is detrimental to fatigue strength and adhesion of the material to the substrate.

Particle size of the metal powder constituent may preferably lie in the range from 0.5 to 10 $\mu\text{m}$  and more

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preferably between 0.5 and 5 $\mu\text{m}$ .

Alternative metal powder constituent combinations to Al/W described above may include Al/Sn; Ag/Cu; Cu/W. However,  
5 it will be appreciated by those skilled in the art that other combinations may be employed, e.g. Ag/W and also that the individual powders may not necessarily be elements but may also be alloy particles such as stainless steel, brasses or bronzes, for example. Whilst  
10 lead or lead-containing materials are beneficial for bearing properties, such materials are now non-preferred due to their environmental and safety disadvantages.

A fluoropolymer may be included in the bearing material  
15 for its beneficial effect on material frictional properties and its self lubricating effect. A suitable material may be polytetrafluoroethylene (PTFE), however, other fluoropolymers may be used but the performance is generally inferior to PTFE.

20 A suitable range for fluoropolymer content may be from 1 to 15vol% with 2 to 8vol% being a preferred range. Too high a content of fluoropolymer reduces the matrix hardness and strength by an unacceptable degree.

25 Particle size of the fluoropolymer desirably lies in the range from 1 to 5 $\mu\text{m}$ . A size range of 2 to 3 $\mu\text{m}$  is preferred.

30 The term "ceramic" powder is used in a general sense to include additions of non-metallic, inorganic particulate materials which serve to improve the wear resistance and strength of the polymer matrix. Examples of such materials may include oxides, nitrides, carbides,

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sulphides, silicates and the like. Tests have been conducted using alumina, talc and glass beads as additions to the polymer matrix.

- 5 Of the various alternative ceramic powders which have been tested, three appear to be particularly useful in respect of their effects on various properties, these materials are: alumina, boron nitride and talc.
- 10 Alumina appears to have a beneficial effect in that it gently polishes the surface of the cooperating shaft journal to render the journal surface less abrasive to the bearing surface thereby decreasing wear thereof.
- 15 Boron nitride appears to be particularly beneficial, especially where the particle morphology is in platelet form. Tests indicate that boron nitride of hexagonal crystal structure in platelet form co-operates with the lubricant to provide enhanced compatibility resulting in  
20 better seizure and scuffing resistance. Contrary to this, tests with boron nitride of cubic crystal structure in spherical or nodular particle form have resulted in seizures under fatigue testing.
- 25 Talc, whilst being a very soft material, in contrast to boron nitride, for example, appears to reinforce the polymer matrix especially at the edges adjacent the axial bearing ends where some shrinkage otherwise occurs during curing of the polymer resulting in greater edge wear in  
30 use when talc is not present. However, it has also been found that boron nitride also fulfils this function of minimising shrinkage and wear effects at bearing edges. Therefore, the use of both talc and boron nitride together is not considered necessary and the use of boron  
35 nitride is to be preferred due to its greater beneficial

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effect on performance.

Content of ceramic powder may range from 0.5 to 20vol%. Above 20vol% the material becomes too hard and inflexible  
5 whereas below 0.5vol% the beneficial effects on wear and matrix strength are not fully realised. A content of 2 to 20vol% is preferred.

Silica may be present in the range from 1 to 20vol%.

10

Silica is distinguished from the ceramic powder additions discussed above as it is not added as a powder and in some formulations has further, more far reaching, effects on the polymer material and bearing as a whole than do  
15 the ceramic powder additions above. Addition of silica may be made to the epoxy-based matrix material in the range from 2 to 15vol%. Silica has the effect of strengthening the matrix and has a beneficial effect on wear resistance. Below 2vol% the effects are not  
20 sufficiently realised whereas above 15vol% the matrix becomes too hard and inflexible. 4 to 10vol% is a preferred range.

The type of silica is important as this has a significant  
25 effect on the bearing characteristics of the material. Preferably, the particle size of silica should be in the range from 20 to 50 nanometres. The type of silica used actually assists the adhesion of the polymer layer to the substrate. The chemical form of silica used possesses "-  
30 OH" groups on the surface of the particles and which bond to a metallic substrate surface and thus, improve both the strength and the fatigue resistance of the material by the improved bond strength. Thus, the silica used is not merely a free particle within a matrix but a

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"reactive" form of silica in which the -OH groups are reactive and polar and which thus improve adhesion.

Desirably, the total content of solids additions to the plastics matrix should not exceed 35vol% irrespective of the total individual constituent contents specified above. In general, the total solids content (pigment volume content, PVC) of additions to the matrix may preferably lie in the range from 10 to 30vol% and, more preferably within the range of 20 to 30vol%.

Preferably, the bearing material according to the present invention also includes a further addition of a separate adhesion promoting agent. Such adhesion promoting materials may be based on silane materials and are effective by means of one end of the silane molecule bonding by cross linking with the polymer matrix and the other end of the molecule, which possesses a high proportion of "-OH" groups bonding with the metal substrate. An addition in the range of 0.2 to 3vol% is preferred. Examples of suitable materials may include bis-(gamma-trimethoxysilylpropyl)amine and gamma-glycidoxypolytrimethoxysilane.

The bearing according to the present invention may comprise one of several different forms: for example, the strong backing material may be steel and have deposited thereon a layer of a first bearing material, the first bearing material having deposited thereon a second, polymer-based, bearing material according to the present invention. In this instance the first bearing material may comprise a metallic bearing material based on an aluminium alloy or a copper alloy, for example.

In some circumstances the layer of the first bearing

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material may itself constitute the strong backing material per se. In this instance a tin-bronze material may be used, for example.

- 5 Where the polymer-based bearing material according to the present invention is deposited upon a layer of a first bearing material, then it may have a thickness in the range from about 5 to 40 $\mu\text{m}$ . A thickness range of 10 to 30 $\mu\text{m}$  is, however, preferred.

10

- It is also envisaged that the polymer-based bearing material of the present invention may be deposited directly upon a strong backing material which itself is not a bearing material in the recognised sense. An example of this would be a steel backing with 15 a layer of the polymer-based bearing material deposited thereon. In such a construction, the thickness of the polymer-based bearing material according to the present invention may be greater than where there is an intervening layer of first bearing material. In this construction, the thickness of the layer of polymer-based 20 bearing material may lie in the range from 40 to 100 $\mu\text{m}$ . A preferred range may be from 40 to 70 $\mu\text{m}$ .

- The polymer-based bearing materials of the present invention may be applied as a liquid to the substrate. Moreover, the polymer-based materials may be thinned with appropriate solvents and sprayed by known techniques onto a desired substrate. Control of 25 layer thickness is good and thicker layers may be formed by the spray deposition of a plurality of layers, for example.

- 30 Where the method of deposition is by the spraying of a thinned layer or layers, the spayed material may first be given a low temperature heat treatment to remove solvent followed by a further consecutive heat treatment to cure the polymer matrix.

In order that the present invention may be more fully understood, examples will now be described by way of illustration only.

Two different materials were made for testing based on  
5 the epoxy/phenolic material and on the polyimide/amide material.

The compositions of these materials are set out in Table 1 below.

Concentrations of materials by volume, in cured product, based on epoxy/phenolic and PI resin.

TABLE 1

Raw Materials	Particle shape	Approximate Particle size	Formulation Ref			
			01-008 S1	01-008 H1	01-008 X	01-008 K1
Epoxy/Phenolic			69.3			01-008 L1
Polyimide/polyamide		79.303		80.75	69.90	69.90
Tungsten	Spherical	5 micron	6.58	4.5	9	
Aluminum	Spherical	5 micron	4.48	18.09		
Silica	Spherical	50 nanometers	5.35	4.1		
Polytetrafluoroethylene	Spherical	1-3 micron	3.0	1.8	6.3	6.3
Aluminium	Irregular	5 microns			9.3	9.35
Ceramic beads	Spherical	5 – 10 microns			14.4	14.4
Aluminum oxide	Irregular	1-3 micron	5.65			
Bis(gamma-trimethoxysilylpropyl)amine			0.96	0.96		
Polyester dimethylpolysiloxane			0.027			0.05
<b>Processing parameters</b>						
Curing temperature			190oC	190oC	190oC	190oC
Curing time			30 min	20-30min	30 min	30 min
Thickness on Copper alloys & Aluminum			15µm	15µm	15µm	15µm
Thickness on steel			50 – 100µm	50 - 100µm	50 - 100µm	50 - 100µm
Solvent content			Approx 700	Approx 725	Approx 870	Approx 825
Solvent content m/L						Approx 780

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Raw Materials	Particle shape	Approximate Particle size	Formulation Ref		
			01-008 327	01-008 326	01-008 C1
Epoxy/Phenolic			61.75	79.87	61.75
Polyimide/polyamide	Spherical	5 micron	17.25	9.34	17.25
Tungsten	Spherical	5 micron	11.6		11.6
Aluminium	Irregular	30 microns			
Tin	Spherical	1-3 micron	7.7	4.24	7.7
Polytetrafluoroethylene	Irregular	5 microns	6.3		6.3
Aluminium	Spherical	5 – 10 microns			
Ceramic beads	Irregular	1-3 micron			
Aluminium oxide	Irregular	10-15μm			
Silica	Lamellar	Approx 5 microns			
Stainless Steel					9.3
Bis(gamma-trimethoxysilylpropyl)amine					
Polyester dimethylpolysiloxane		1.7	0.19	1.7	0.19
Processing parameters					0.55
Curing temperature		190oC	185oC	190oC	185oC
Curing time		30 min	20 min	30 min	20 min
Thickness on Copper alloys & Aluminium		15μm	15μm	15μm	15μ
Thickness on steel		50 – 100μm	50 – 100μm	50 – 100μm	50 -100μm
Solvent content		Approx 870	Approx 760	Approx 870	Approx 760
Solvent content ml/L					

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The concentrations of additions to the matrix are by volume% in the cured material based on the density of the particular matrix polymer in each case.

- 5 Reference in "processing parameters" to copper alloys and aluminium alloys refers to the substrate material on which the polymer is deposited. The substrate in all cases is further provided with a strong backing material of steel.
- 10 Bearings were formed from coated substrates and tested for wear in a known "Viper" wear test rig and for fatigue strength in a known "Sapphire" fatigue test rig. Test conditions for each type of test are given below.
- 15 Viper wear tests are accelerated wear tests and have conditions:

Load	8kgs
Shaft diameter	46.25mm
Shaft roughness	0.2 Ra
Shaft speed	500 rev/min
Oil temperature	120°C
Test duration	10 to 360 mins.

- 15 The bearings were weighed before and after each test and the weight loss taken to represent resistance to wear. The weight losses were converted into volume losses to permit accurate comparisons of wear behaviour.

- 10 Sapphire fatigue tests were conducted on half bearing samples comprising a steel backed, cast copper-lead alloy bearing metal lining and having an overlay coating according to the present invention sprayed in the bore thereof. Test rig temperature was 80°C; running periods of 20 hrs at each load were used with load increments of 7kgs

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at each time period. Results of the tests are given below in Table 2.

**TABLE 2**

5

Material	Coating Thickness	PVC	Substrate	Wear Volume loss mm <sup>3</sup>	Time minutes	Fatigue strength MPa	Time Hours
Modified Epoxy Al/W H1	25µm	30%	VP2	0.122	60	76	100
Polyimide Al/W 327	12µm	30%	VP2	0.505	60	103	180
Polyimide Al/W 326	18µm	30%	VP2	0.501	60	83	120
Polyimide Al/W C1	10µm	30%	VP2	0.463	60	90	140
Polyimide Al/W C1	25µm	30%	VP2	0.463	60	90	140
Polyimide Al/W M1	15µm	20%	F90	0.122	60	76	100
Polyimide Al/w Y	15µm	15%	VP2	0.122	60	103	180
Polyimide Al/W/Ceramic K1	15µm	20%	F90	0.027	60	83	120
Polyimide Al/W/Ceramic L1	15µm	20%	F90	0.022	60	76	100
Polyimide Al/W/Alumina S1	15µm	20%	VP2	0.24	60	76	100
Polyimide Al/Stainless steel/Alumina R2	15µm	20%	VP2	0.00	60	97	160

Table 3 below gives comparative data on known metallic overlays and shows Viper (wear volume loss) and Sapphire (fatigue strength) results on known metallic electro-deposited overlay materials.

**TABLE 3**

Material	Coating Thickness	Substrate	Wear Volume loss mm <sup>3</sup>	Time Mins	Fatigue strength MPa	Time hrs
Pb-10Sn-2Cu	12µm	VP2	7.8	12	69	80
Pb-In	12µm	VP2	10.2	12	76	100
Pb-10Sn-1 Alumina	12µm	VP2	0.5	60	83	120

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The polymer overlay compositions were all sprayed onto a copper-based (VP2) or aluminium-based (F90) bearing alloy.

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The column headed "PVC" denotes the total "pigment volume content" in the matrix and comprises metal powder, silica, fluoropolymer and all other additions in the final, as-cured and tested bearing material.

5

It may be seen that the wear and fatigue resistance of polymer based overlays according to the present invention and as set out in Tables 1 and 2 are in most cases superior to metallic overlays as set out in Table 3. Only the 10 composite overlay comprising a co-electrodeposited alumina phase (Pb-10Sn-1alumina) in the overlay matrix has wear and fatigue resistance approaching that of the polymer overlays according to the present invention. However, the prior art metallic overlays are costly to produce, especially the 15 alumina containing composite material and are also environmentally undesirable being based on a lead matrix. Overlays according to the present invention may be made up in bulk and applied with relative ease by known, well understood and controllable spraying processes.

20

Tables 4 to 7 below give the compositions of some additional bearing overlay layers which have been tested under the Viper wear test regime discussed above. Table 9 shows the results of those wear tests. As will be 25 immediately apparent that the total wear volume loss is extremely low

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5 TABLE 4

Material 151B - L5	Wt of materials/gms	%wt	Volume of materials/mls	Volume Solids	vol% in dried layer
Epoxy resin	103.60	23.20	21.09	7.38	38.3
Amino	40.30	9.03	9.03	5.42	22.1
Vinyl resin	9.00	2.02	2.02	2.02	10.5
Resin %					70%
Talc	17.50	3.92	1.37	1.37	7.1
Al	39.10	8.75	0.37	0.24	1.3
Stainless steel	48.70	10.90	1.55	1.4	7.3
PTFE	6.40	1.43	0.65	0.65	3.4
Al <sub>2</sub> O <sub>3</sub>	12.80	2.86	0.79	0.79	4.1
Fillers		62.11		19.27	
PVC					30.4%

TABLE 5

10

Material 151A - K5	Wt of material gms	%Wt	Volume of materials/mls	Volume solids	vol% in dried layer
Epoxy Resin	103.60	21.46	19.5	6.8	34.64
Amino	40.30	8.35	8.35	5.1	25.98
Vinyl resin	9.00	1.86	1.86	1.86	9.47
Resin %					70.09%
Talc	17.50	3.62	1.27	1.27	6.46
Al	39.40	8.16	3.02	1.96	9.98
Tungsten	121.80	25.22	1.30	1.30	6.62
PTFE	6.40	1.32	0.6	0.6	3.05
Al <sub>2</sub> O <sub>3</sub>	12.80	2.65	0.74	0.74	3.76
Fillers		40.97			
PVC					29.87%

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**TABLE 6**

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Material 152A - O5	Wt of materials/gms	%wt	Volume of materials/mls	Volume Solids	vol% in dried layer
Polyimide	56.00	35.12	29.3	12.9	56.87
Vinyl resin	4.80	3.01	3.01	3.01	13.27
Resin%					70.14%
Talc	6.60	4.13	1.44	1.44	6.34
Al	12.15	7.61	2.8	1.82	8.024
Stainless steel	15.00	9.4	1.34	1.20	5.29
PTFE	2.50	1.56	0.71	0.71	3.13
Al <sub>2</sub> O <sub>3</sub>	9.20	5.76	1.6	1.6	7.05
Fillers		28.46			
PVC					29.84%

**TABLE 7**

Material 152B – P5	Wt of material/gms	% Wt	Volume of materials/mls	Volume solids	vol% in dried layer
Polyimide	56.00	30.82	25.68	11.29	56.76
Vinyl resin	4.80	2.64	2.64	2.64	13.27
Resin%					70.03%
Talc	6.60	3.63	1.27	1.27	6.38
Al	12.15	6.68	2.47	1.60	8.04
Tungsten	37.25	20.50	1.06	1.06	5.32
PTFE	2.50	1.37	0.62	0.62	3.11

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Al <sub>2</sub> O <sub>3</sub>	9.20	5.06	1.41	1.41	7.09
Fillers		70.7			
PVC					29.94%

**TABLE 8**

Material	Wt of material/gms	% Wt	Volume of materials/mls	Volume Solids	vol% in dried layer
151 - K6					
Epoxy 1	62.10	13.17	11.97	4.2	18.3
Epoxy 2	29.00	6.15	5.6	4.2	18.3
Amino	48.25	10.23	10.23	6.14	26.9
Vinyl resin	7.20	1.53	1.53	1.53	7.7
Resin%					71.9%
Boron Nitride	15.00	3.18	1.51	1.51	6.76
Al	46.20	9.8	3.62	2.36	10.56
Tungsten	92.10	19.53	1.01	1.01	4.52
PTFE	6.80	1.44	0.65	0.65	2.91
Al <sub>2</sub> O <sub>3</sub>	12.80	2.71	0.75	0.75	3.36
Fillers		36.66			
PVC					28.1%

5 TABLE 9

Material	Coating Thickness ( $\mu\text{m}$ )	PVC	Wear Volume loss ( $\text{mm}^3$ )	Test Duration (mins)
151B-L5	15	30	0.024	60
151A-K5	15	29.9	0.18	60
152A-05	15	29.8	0	60
152B-P5	15	29.9	0	60

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It may be seen from Table 9 that the wear rate of the material shown in Tables 4 to 7 is very low and even in the worst case is about 35% that of the best comparable metallic overlay comprising alumina.

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